THE NEBULAE.*

BY HEBER D. CURTIS.

In the four lectures of the Stahl series which have preceded this one you have heard about that portion of the universe to which our own little earth belongs, you listened to what astronomy has to say regarding the planets of our solar system and whether they may possibly be inhabited or not, learned something of those mysterious wanderers in our system which we call the comets, studied the surface of that cold and lifeless satellite of ours, the Moon, and the fact was brought home to you that the mighty Sun was only our own particular star, and not a very great or important star at that except for its position as the center of our solar system. In the present lecture we shall consider the nebulae, a remarkable class of objects in the universe without, a universe so vast, of such incomprehensible extent, that our own solar system is but an atom in comparison.

Tho the task is apparently a hopeless one, it may be an advantage if we make the attempt at the start to realize the vastness of this outer stellar universe of which our solar system forms so inconspicuous a part. We can all form some conception of the distance around the Earth, say twenty-five thousand miles, and we can then have some sort of an idea of the distance of the Moon as about ten times as far away. But neither the layman nor the professional astronomer can form any adequate conception of the distance of the Sun, ninety-two millions of miles distant from our Earth. Nor can we have any idea of the distances of the stars from the fact that, at the distance of the average naked eye star, ninety-two millions of miles looks to us of about the same size as a fifty-cent piece in Los Angeles, viewed from San Francisco. Out in this ocean of space a measuring rod a million miles in length is all too short; it would be like trying to measure the distance to Los Angeles with a foot rule. Something a million times larger than this would be better, so the foot-rule which the astronomer ordinarily uses is the distance traveled by

* Fifth Adolfo Stahl Lecture, delivered in San Francisco on March 9, 1917. The lecture was illustrated with many lantern slides, of which a few typical subjects are reproduced in the cuts accompanying this article.

light in one year, which he calls a light-year. A light-year is nearly six trillion miles; that is, take a length of a million miles and lay it down as a measure six million times, end to end. The light-year is not quite six trillion miles, but we need not be particular about a few billion miles more or less. It takes light, then, over four years at the rate of nearly two hundred thousand miles a second, to reach the very nearest of the stars, so such a star is said to be four light-years away. We feel certain that some of the celestial objects are so far away that it takes light a hundred thousand years to make the journey, in other words, we see such objects not as they actually are tonight, but as they were one hundred thousand years ago. But enough of such brain-staggering figures. It is sufficient if we from these facts comprehend a little more clearly that this stellar universe is something wonderful and mighty, far beyond the power of the mind of man to grasp.

What we term the factor of space-distribution is of considerable importance in all theories of the nebulae, that is, the way in which these are arranged with reference to the great mass of the stars, so, at the start, a word or two with reference to the "geography" of the stellar universe will be in place. We can see for ourselves on any clear night that most of the stars are grouped near the Milky Way, and our telescopes and photographs show that this is really the case; the stars are not arranged regularly all thru space, but the great majority of the thousand million or so of stars are grouped in a relatively flat disk, so that the shape of the stellar universe, when we consider the stars alone, is much like that of a thin pocket watch, with our Sun fairly near the center of the region.

Another point which will be of importance later in the lecture is what we may term the factor of space-velocity. All these apparently fixed celestial objects are really moving in all directions at very high rates of speed. Thus we may not speak of the part of space occupied by our solar system, but simply of the part of space which it now occupies, for the Sun and all his retinue of planets is moving thru space at the rate of about twelve miles in every second of time. This seems inconceivably rapid to us, but our Sun is, even at this

rate of speed, quite a slow coach compared with many of the stars. Thus, when the Egyptians commenced to study the heavens five thousand or more years ago, we and our solar system were two trillion miles from where we are tonight. At that rate it would take us fifty or sixty thousand years to reach the very nearest of all the other stars, provided we were going exactly in that direction, which we are not. When you leave the hall at the close of this lecture the Sun and all our system and all of us with it will have traveled about forty-three thousand miles from the place where it was when you sat down. If I should happen to talk ten minutes too long we should be seven thousand miles beyond the corner where we should have got off!

But neither the two trillion miles which our system has traveled since the days of the Egyptians, nor the equal or greater movements which all the stars have made in that interval, have made any essential difference in the general appearance of the heavens, for two trillion miles is not a very long way as distances go in the outer world of space. The Egyptian saw his night sky tilted at a different angle and had a different pole star than our own, because of a progressive change in the position of the Earth's axis, but the constellations looked practically the same then as they do now; tho all the stars are moving at these rapid rates of speed, it takes much longer than five thousand years for these motions to show so as to be very perceptible without a telescope and accurate measures.

Now out in this limitless ocean of space we see just two great classes of objects, the stars, and the nebulae; while our subject is the nebulae, the stars will, of necessity, be occasionally mentioned as well. As for the stars, our great telescopes and the photographic plate tell us that there must be a thousand million or so, separated from each other and from us by trillions and quadrillions of miles. But there is a smaller number of objects of an entirely different class than the stars, objects which in a telescope look like very faint luminous clouds, which is the reason they have been given the name "nebula" from the Latin word for cloud. There are several hundred thousand of these nebulae, ranging in apparent size

from mere specks to great masses covering an area larger than that covered by the Moon. Only a very few of them are large enough or bright enough to be seen without a telescope, and even in the largest telescopes the best of them prove generally to be very disappointing objects to the layman, as they are so faint and indistinct. Their full beauty and wonderful structure is brought out only by photographs of several hours exposure time made with a large reflecting telescope, and the illustrations shown were made in this way by the Crossley Reflector at the Lick Observatory.

In looking at reproductions of the nebulae it is well to try to keep in mind that these remarkable objects are really of enormous size; perhaps the following illustration will assist in forming this impression. We shall not be very far wrong in the statement that the diameter of the average star is from half a million to a million or more miles. Now the thing which is most apt to disappoint the average observatory visitor as he looks thru a great telescope at a star is that it still looks like a star, a mere point. He sees the star much brighter than it would appear to the naked eye, but expects to see something very large, filling the whole field of the telescope, and is at some difficulty to comprehend why the brightest star should still look like a point in the mightiest telescope; it is hard for him to realise that the star is so far away that even a million miles under high magnifying power looks like a point without size. If half a million or so of miles has no size at all, so to speak, at stellar distances, how mighty must a nebula be which covers a space equal to that covered by the full Moon? It will then be evident that many of these bodies must be billions or trillions of miles, even many light-years, across from edge to edge.

While the nebulae take a great variety of form, there are but three main classes, and the following table will show the main features of each class.

THE GREAT DIFFUSE NEBULAE.

Enormous masses of luminous matter; filmy, cloud-like, and generally very irregular. Occur in or near the Milky Way and where the stars are thickest. Frequently associated with "young" stars, never with "old" stars. Speeds low; almost at rest in space. Fairly numerous.

FIGURE 1. THE DIFFUSE NEBULOSITY, MESSIER 8, IN SAGITTARIUS.

FIGURE 2. THE DIFFUSE NEBULOSITY, N. G. C. II 5146.

FIGURE 3. THE DUMB-BELL NEBULA.

THE PLANETARY NEBULAE.

Generally small, clear-cut, bright, and with a central star. They are gaseous bodies. Comparatively rare objects; fewer than 150 known. Tend to congregate in the Milky Way. Average speed much higher than that of the stars.

THE SPIRAL NEBULAE.

Several hundred thousand in number; generally spiral in form. Congregate about the poles of the Milky Way where stars are fewest, and never found in the Milky Way. Speeds enormous, averaging several hundred miles a second. Their light is generally the same as average star-light.

The great diffuse nebulosities are wonderful structures and Figure 1 shows a typical object of this class. In some cases, as in the nebulosity around the *Pleiades,* there is good evidence to believe that the light from these nebulosities is in some way, perhaps by reflection, caused by the bright stars with which they are associated. But in the majority, as The Great Nebula in *Orion,* Messier 8, The Trifid Nebula, and others, the light which comes to us from them tells us very clearly, when analyzed in our spectroscopes, that these are truly gaseous bodies. They contain the gases hydrogen, helium, and something which for lack of better knowledge, we call "nebulium". Just how they shine we do not fully know; we have evidently to do here with matter in a very rare and perhaps primordial state, and it may be that their light is in part due to some form of electrical excitation. As far as their actual density is concerned they must be exceedingly rare bodies. Among our reasons for this belief is the easily calculated fact that were the substance of the enormous nebula in *Orion* anywhere nearly as heavy or as dense as ordinary air the great mass would weigh so much that it would be drawing all the neighboring stars and our Sun as well swiftly toward it by its gravitational power. Sometimes the region immediately around one of these diffuse nebulosities is singularly devoid of stars. Figure 2 shows this in a striking manner. The best explanation appears to be that around the inner luminous part of such a nebula there lies a great mass of dark matter which obliterates the stars in the background. These diffuse nebulosities are often found associated with stars and in every such case the star is one of the class which, from the character of the light it sends us, is believed to be a

"young" star; never do we find this diffuse nebulosity associated with stars of "old" types. Bearing in mind that these diffuse nebulosities are always found in or near to the Milky Way where the stars are thickest, we can see that there are very good reasons for supposing that the great diffuse nebulosities may well be regarded as the primordial stuff from which stars are made.

Tho the second class of nebulae, the planetaries, is so small a one, it is nevertheless of very great interest. Figure 3 shows a typical object of the class. Their light shows them to be of gaseous constitution; they are nearly all rather small and oval or round, and most of them show a central star. They tend to congregate in the Milky Way and where the stars are found in greatest numbers. Many of them are of exceedingly complicated structure, and, because of recent discoveries with the spectograph, we know that they are revolving. But they are a very puzzling class. We do not know as yet how they can take these complex forms and show certain motions as they do under the ordinary laws of gravitation alone; perhaps other forces, such as radiation pressure, come into play as well. We would like to think of them as in that stage of nebular condensation and stellar evolution which comes just before true stars are formed.* But there are several difficulties in the way of accepting this theory. In the first place, the planetaries are comparatively rare objects; out of so many hundred thousand stars in all stages of development it is very strange, in fact inexplicable, that there should be fewer than one hundred and fifty at this particular early stage. Then too, their space velocities are very much higher than that of the average star. Why should the planetaries stand so decidedly apart in this respect, and how can this gap be bridged over? Tho but a theory as yet, perhaps the most acceptable hypothesis, because of their high speeds and small numbers, is that the planetary nebulae are to be regarded as a somewhat sporadic case in stellar evolution, arising thru some collision or cataclysm, and not to be regarded as cases typical of the general run of stellar development.

* They are very closely allied in spectrum with a comparatively rare class of stars known as the Wolf-Rayet stars.

 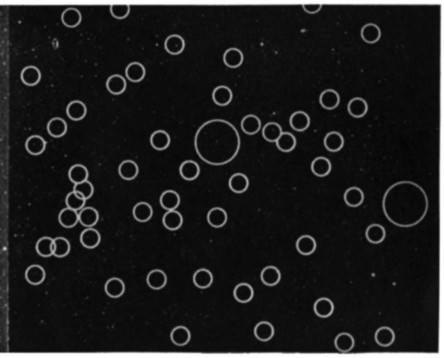

FIGURE 4, AT LEFT. REGION IN THE MILKY WAY SHOWING TEN TO TWENTY THOUSAND STARS, ONE PLANETARY (N. G. C. 6563), AND NO SPIRALS.

FIGURE 5, AT RIGHT. REGION NEAR N. G. C. 2507, SOME DISTANCE FROM THE MILKY WAY, SHOWING FEW STARS AND FIFTY-THREE SMALL NEBULAE, INDICATED BY RINGS. THE AREA OF EACH HALF IS SOMEWHAT LARGER THAN THAT COVERED BY THE FULL MOON.

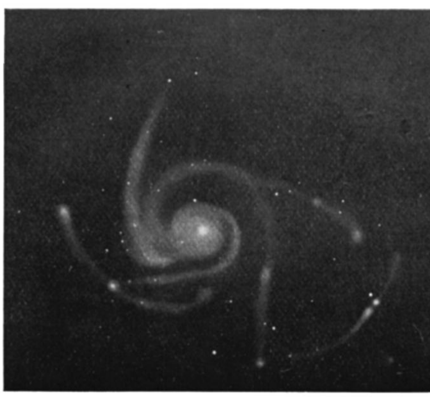 

FIGURE 6, AT LEFT, IS A DRAWING OF THE SPIRAL NEBULA, MESSIER 101, MADE BY HUNTER IN 1851 WITH THE 6-FOOT REFLECTOR OF LORD ROSSE.

FIGURE 7, AT RIGHT, A PHOTOGRAPH OF THE SAME NEBULA.

When we pass on to the third subdivision, the great class of spiral nebulae, we are on much less certain ground. Prior to the introduction of photography there were fewer than ten thousand nebulae known. It was Director Keeler, of the Lick Observatory, who first really showed the great power of photography and the reflecting telescope in the depiction and discovery of nebulae. Some of the very largest of this last class of nebulae had, it is true, been seen visually to be of spiral form, but Keeler's photographs showed, first,—that the great majority of the nebulae were spirals in form, and, secondly,—that their numbers were far greater than had before been supposed. Figure 4 shows a small part of the Milky Way where the stars are very closely packed so that they seem almost to touch one another, tho in reality trillions of miles apart. In such regions as this we never find a single spiral nebula. Figure 5 is from a negative taken some distance from the Milky Way. The area covered is somewhat larger than would be covered by the disk of the full Moon, and it will be noticed that the stars are comparatively few in number. But many nebulae are seen on the original negative; these are too faint and too small as a rule to show in the cut, so the position of each one is indicated by a small ring. Most of these small nebulae are probably spirals. It may be seen, then, that the spirals occur in great numbers in certain definite parts of the sky; the estimates as to their total number range from two hundred thousand to half a million. It should be emphasized, also, that they never occur in the regions where the stars are thickest, but seem to abhor these regions, congregating near the poles of the Milky Way. Figures 6 and 7 will serve to show how immeasurably photography has improved our knowledge of the nebulae. The first is a copy of a drawing made by Mr. Hunter in 1851 with the six foot reflector of Lord Rosse, and the other a photograph of the same object. It will be evident that there is simply no comparison between the two, and that the beautiful and delicate structure of the photograph was entirely invisible in a powerful telescope. The human eye is a wonderfully delicate instrument, but it can see a faint object no better or no more clearly after gazing at it for an hour than it could in the first few

seconds; the photographic plate, on the other hand, keeps adding up all the impressions of each second or fraction of a second it is exposed to the object, and thus with long exposures can show us objects far too faint for the human eye alone, tho aided by the greatest telescope in existence.

Tho the general characteristics are the same, the spirals exhibit a great variety of form. Sometimes there are but two prominent whorls, as in Figure 8; at other times the structure is much more complicated, as in Figure 9. Occasionally the spiral whorls will lie so close together that a ring appearance is shown, but in most cases the structure is more open. Most frequently the spiral appears like an elongated oval (Figure 10) because it is essentially a flat, disk-like structure, and seen at an angle, but occasionally it lies so nearly straight across our line of sight that it appears as almost round (Figure 7). Then again we see quite a number almost exactly edge on and can get a vivid idea of the fact that the spiral is not a sphere in general outline, but flat and lens shaped. Many of these edgewise spirals show a very interesting phenomenon. Figures 11, 12 and 13 show this very clearly. There is very evidently a great band of absorbing matter all around the circumference of these spirals, which cuts off all view of the matter in the nebula in a lane running along its length. Figure 13 shows this in a most striking manner; the dark lane is so clear-cut that it appears almost like a streak of black paint along the image of the nebula.

Now what has modern astronomy to say as to the constitution of these beautiful objects, the spiral nebulae? May we think of them as representing a certain early stage in the evolution of the stars, or in the formation of such a system as our own solar system? Do they, as was long held by astronomers, give us ocular evidence in support of some sort of nebular hypothesis, and are they the existing representatives of that primeval stage when our own solar system was an extended, whirling mass of primordial gas? Is it possible to regard them as in the first of the stages so well put by Tennyson in "The Princess"?—

> "This world was once a fluid haze of light,
> Till toward the center set the starry tides
> And eddied into suns that, whirling, cast the planets."

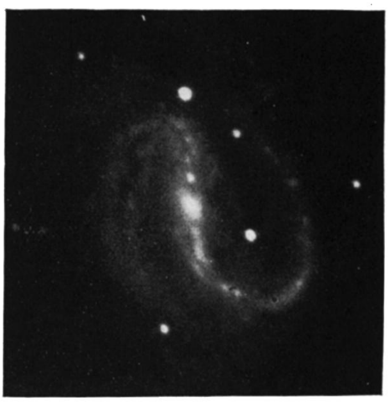

Figure 8. The Spiral Nebula, N. G. C. 7479.

Figure 9. The Spiral Nebula, Messier 51.

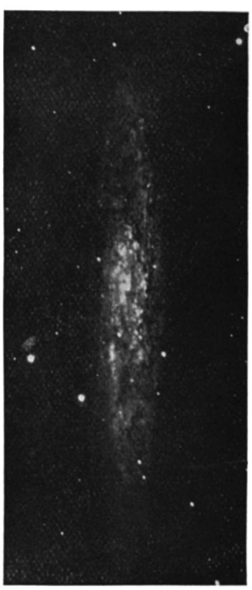

Figure 10. The Spiral Nebula, N. G. C. 253.

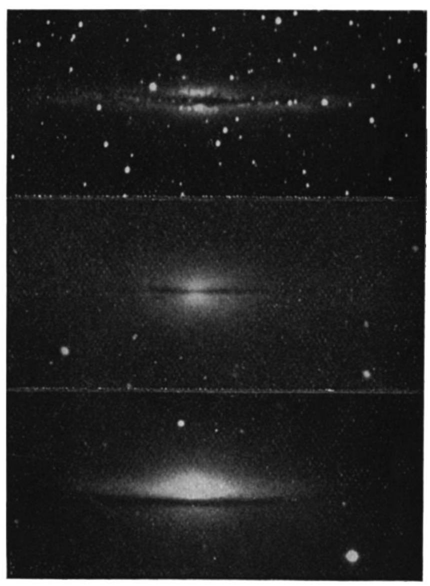

Figure 11. N. G. C. 891.
Figure 12. N. G. C. 7814.
Figure 13. N. G. C. 4594.

From the form of the spiral nebulae we feel certain that they must be in rotation; we have some slight evidence of this in the fifteen or twenty years during which they have been under photographic observation, and the temptation is a strong one to place these great rotating spirals as a first stage in the evolution of stars or solar systems. The majority of astronomers still believe that our solar system was formed in accordance with some sort of nebular hypothesis, tho, for a number of weighty technical reasons impossible to detail here, the well-known nebular hypothesis of Laplace, in just the form in which he put it forward, is no longer accepted.

But, tempting as such a theory of the spirals is, there are a number of very strong objections to it, objections which depend largely upon the two factors of space velocity and space distribution, which were mentioned briefly at the beginning of the lecture. We may sum up in the following table what we know at present of the space velocities of the various classes of objects in the stellar universe.*

THE FACTOR OF SPACE-VELOCITY.

Diffuse Nebulosities; velocities low.
The Stars; velocities appear to increase with stellar age.

Class B;	average	speed	8	miles	per	second
Class A	"	"	14	"	"	"
Class F	"	"	18	"	"	"
Class G	"	"	19	"	"	"
Class K	"	"	21	"	"	"
Class M	"	"	21	"	"	"

The Planetary Nebulae; average speed 48 miles per second.
The Spiral Nebulae; average speed 480 miles per second.†

It will be seen that, as far as their space velocities are concerned, the great diffuse nebulosities fit in well as a starting

* The stars are divided into a relatively small number of types or classes in accordance with the character of the light they send to us. Classes B and A are the bluer stars, in whose light hydrogen, helium and other gases are prominent, and are generally supposed to be the youngest stars; Classes F and G are yellower, more like our Sun, and show the presence of many metals; Classes K and M are redder and thought to be stars of relatively advanced age. While other arrangements of these classes, as indicating relative star ages, have been put forward, the generally accepted order of stellar age is as given in the table.

† The speed given for the spiral nebulae is somewhat uncertain, as this has been observed for a comparatively small number of spirals as yet. The assumption is also made that their motions are in all directions. Future work may change the value, but it seems certain that it will remain very large.

point in the evolution of the stars, and we have seen that these are, if associated with stars, always connected with those classes of stars which are believed to be the youngest. On the other hand, the planetaries do not fit in, unless we should place them at the end of the stellar progression, or, as is perhaps better, regard them as exceptional cases. And the spiral nebulae do not fit in at all; their almost unbelievable velocities place them in a class entirely apart from the great mass of the stars.

Taking up the even more important factor of space distribution, the following table will show roughly the apparent location of the spiral nebulae with reference to the universe of stars which we call our galaxy.

THE FACTOR OF SPACE-DISTRIBUTION.

100,000 ± Spiral Nebulae
Distance unknown.

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The Milky Way and stellar universe
is believed to be roughly lens-shaped and about
3,000 by 30,000 or more light-years in extent. In this space
occur nearly all the stars, nearly all the diffuse nebulosities, nearly all
the planetary nebulae, nearly all new stars, nearly all
clusters, nearly all the variable stars, etc., but
NO SPIRAL NEBULAE.

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100,000 ± Spiral Nebulae
Distance unknown.

The factor of space distribution is then entirely at variance with the hypothesis of the spiral nebula as a starting point in the formation of stars or of our own solar system.

The spirals are intrinsically so very faint that it is a matter of great difficulty to secure spectroscopic observations which will throw additional light on their composition, and this work has been done for only a few of the brightest members of the class. Here we find a very puzzling fact. The light which these objects send to us, when analyzed in our spectroscopes,

tells us that they are, in general, not gaseous, but of such constitution that their light is just the same as would be expected to come from a great cloud of stars. The future may possibly bring to light new facts which will enable us to give some other explanation, but our present evidence, so far as it goes, leads to the belief that the spirals are composed of great clouds of stars so infinitely distant that we can not make out the individual stars, much as our own Milky Way, which is seen in the telescope to be made up of millions of closely packed stars, to the unaided eye appears as a faint, nebulous, luminous band across the sky.

This characteristic of their light, then, together with their peculiar distribution, as a class, apparently apart from our stellar system, has given rise to what is known as the "island universe" theory of the spiral nebulae, namely, that these objects are really separate galaxies or universes of stars. There are some difficulties in the theory, but we have at present very little evidence to make any other theory of the spiral nebulae a more probable one. On this theory, too, could we be transported out into space a distance of hundreds of thousands or millions of light-years to where the spirals are situated and look back from that point at our own particular Milky Way and stellar universe, it would perhaps appear to us as a spiral nebula. The attempt has been made to depict our stellar universe as a spiral in general arrangement, with the Sun located fairly near to the center of the spiral.

Why, it may be asked, should our galaxy be situated thus in such a peculiar way about half way between two great groups of other universes at enormous distances from us, with no other universe relatively close to our own, and with none at all visible around the edge of our own, that is, beyond the circumference of our Milky Way? This peculiar arrangement is indeed a puzzle on any theory of the spirals. Perhaps the only explanation which can be suggested is that outside our Milky Way and nearly in its plane is a great ring of absorbing matter somewhat like those which are found in certain edgewise spirals (Figures 11, 12, and 13), and that this matter cuts off from our view all other universes which we would expect to lie beyond and in line with our Milky Way. Then, too, the

analogy of our Milky Way as a spiral must not be expected to prove too much. Nearly all spirals have a well-defined concentration at their centers, marked either by an almost stellar nucleus or by an almost spherical enlargement of the nebular mass around the center, as is well seen in numerous photographs of edgewise spirals. There is pretty certainly no such great concentration of stars at the center of our own galaxy, supposing that it is to be regarded as a spiral. However, there are a number of very flat spirals which show no such mass concentration at the center, but they are scarcely typical of the class.

As a substitute for the Kant-Laplace nebular hypothesis Professors Chamberlin and Moulton have recently propounded what has been called the planetesimal hypothesis as an explanation of the spiral nebulae and the evolution of our solar system. The theory postulates, in brief, that a spiral nebula would be formed as a result of the disruptive tidal effects produced by the close approach of two massive stars. It has been well worked out and appears very plausible in what may be termed its mathematical and mechanical aspects; it does not seem impossible that our solar system might thus have been formed from a diminutive spiral nebula. But the theory can as yet offer no explanation for the fact that the light sent us by the spirals seems to be the same as that from a cloud of stars, nor for their phenomenal space velocities. Why, too, if the spirals are formed from close stellar approaches, should we find them where the stars are fewest, and never occurring where the stars are thickest and where, if at all, close stellar approaches should be common?

It is certainly a wonderful, a brain-staggering conception, more tremendous even than any other of the mighty ideas and facts of astronomy, that our own stellar universe may be but one of hundreds of thousands of similar universes. It is a familiar saying that, "An undevout astronomer is mad" This can not be interpreted too literally; there are many astronomers who are certainly not mad, who could not, by any stretch of the imagination, be termed devout, in the ordinary acceptance of that term. But, in a larger sense, the saying is a true one. Familiarity with these mighty concepts most

certainly does not breed contempt, does not dull our awe at the mightiness of the universe in which we play so small a part. It is very doubtful if any of those who are seriously studying the heavens ever lose their feeling of reverence for this supremely wonderful universe and for Whoever or Whatever must be behind it all.

PLANETARY PHENOMENA FOR MAY AND JUNE, 1917.

By Malcolm McNeill.

PHASES OF THE MOON, PACIFIC TIME.

Full Moon...May	6, $6^h 43^m$ P.M.		Full Moon..June	5, 5^h	7^m	A.M.
Last Quarter. "	13, 5 48 P.M.		Last Quarter "	11, 10	38	P.M.
New Moon... "	20, 4 47 P.M.		New Moon. "	19, 5	2	A.M.
First Quarter. "	28, 3 33 P.M.		First Quarter "	27, 8	8	A.M.

The third eclipse of the year is *a partial eclipse of the Sun* on June 19. It can be seen from no part of the United States except the extreme Northwest in the early morning. The maximum obscuration is less than one-half of the Sun's diameter. As seen in the United States the obscuration is only a small fraction of this. The principal regions of visibility lie in the North Arctic zone.

The summer solstice occurs June 21, 4^h 14^m Pacific Time, and the Sun reverses its northerly motion, beginning to move southward.

May and June, 1917, give rather a poor opportunity for observation of the planets since all of the conspicuous ones except *Saturn* are very near the Sun. There are a number of close and interesting conjunctions, but only a few of them can be observed.

Mercury is an evening star at the beginning of May setting more than an hour and one-half after sunset, and under good weather conditions may be seen in the evening twilight during the first few days of the month; but its distance from the Sun lessens rapidly and inferior conjunction is passed on May 16, the planet then becoming a morning star. It will remain such until July 12. Spring and summer observations of *Mercury* as a morning object are not usually easy as the planet